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Evaluation of COAMPS Mesoscale Modeling in the Persian Gulf Region

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OBJECTIVE

The US Navy conducted a Ship ASW Readiness and Effectiveness Measuring exercise (SHAREM 110) in the Persian Gulf during 5-17 February 1995. As part of SHAREM, additional mesoscale measurements were made by ships and aircraft. After the exercise, the Naval Research Laboratory, Monterey ran the research version of the Navy Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) for the entire SHAREM period, without incorporating the mesoscale observations into model data assimilation.

The purpose of this research is to study the mesoscale features in the SHAREM data set and to evaluate the COAMPS predictions of these phenomena. The period of 8-11 February 1995 includes three distinct synoptic and mesoscale phenomena, which will be studied in this paper. A mesoscale disturbance is evident in ship soundings and aircraft data on 8 February, in advance of a cold front. The front passed through the Persian Gulf on 9 February, and ship and aircraft data for that day shows subsidence, drying, and establishment of a strong inversion behind the front. A Shamal occurs on 10-11 February. Aircraft and ship data on 11 February provide in situ measurements of the Shamal and the resultant deep mixed layer in the Persian Gulf. This paper includes evaluations of COAMPS at three separate times: 06-12 UTC 8 February, 06 UTC 9 February, and 06 UTC 11 February 1995. In addition, evaluation of COAMPS for a period of strong land-sea breeze circulations during 14-15 February will be reported at the conference.

RESEARCH ACCOMPLISHED

As part of SHAREM 110, participating US Navy ships launched rawinsondes and rocketsondes as frequently as every three hours. In addition, the British Meteorological Research Flight (MRF) C-130 aircraft, coordinated through the United Kingdom Meteorological Office, flew low-level sawtooth vertical profiles to measure temperature, moisture, winds, and pressure in the lower atmosphere. The C-130 research aircraft flew sawtooth vertical profiles between 15-1350 meters and sampled cross-sections in three parallel lines over the participating ships in the Persian Gulf. Each cross-section consists of a west-to-east set of 4-5 sawtooth profiles, followed by the return (east-to-west) leg of sawtooth profiles. Byers (1995) describes the synoptic and mesoscale meteorological events during the entire SHAREM experiment period.

The Navy COAMPS nonhydrostatic, mesoscale model was run for the entire SHAREM 110 period by NRL Monterey for COAMPS validation and testing (Hodur, et al., 1996). The COAMPS data assimilation system was used in all model runs. Data assimilation was performed every 12 hours and 24 hour forecasts were produced. The COAMPS nested grids were defined at 81, 27 and 9 km. Boundary conditions were provided from the NOGAPS global model. Forecasts on the 9 km inner grid are used in this study.

8 February 1995

The DMSP visible image for 0529 UTC on 8 February (Fig. 1) shows the prefrontal cloudiness prior to the aircraft measurements. A rope cloud associated with a cold front approaching the Persian Gulf is present on the edge of the image. The satellite data also shows embedded convection, with upper-level cirrus, in the southwest flow over the Persian Gulf. Figure 1 shows the aircraft sawtooth profile cross-section locations are indicated by the lines on the image. The northernmost cross-section flight occurred at 0652-0747 UTC, the middle cross-section at 0754-0900 UTC, and the third (southern) at 0908-1016 UTC. The location of the USNS Silas Bent (SBN) and the USS Lake Erie (LKE) at 06 UTC are indicated by the dots. The Silas Bent and Lake Erie moved to the northwest throughout the day, roughly parallel to the cross-sections.

Note that there is convection in the western portion of each cross-section, but no convection at the eastern end. The variation in MABL structure over the 180 km cross-sections (not shown) is quite surprising. The western end of the cross section shows weak stability with moisture mixed to 1 km while the eastern end of the cross section has a strong inversion at 500m with very dry air above the inversion. See Jordan, et al., (1997) for a more detailed description of the stability changes along the cross section and its impact on EM propagation conditions. Similar variations are present in the other two cross-sections. The line of convection near the west end of the cross section is consistent with the weak stability conditions in the aircraft cross sections.

Figure 2 presents a cross-section of aircraft measured winds for 0829-0900 UTC. Easterly flow occurs below 600 meters. Wind variations associated with the mesoscale disturbance are evident in the winds above 600 meters. There are southerly winds in the eastern half of the cross-section, but light westerly winds in the western half.

Frequent soundings from two ships in the prefrontal region are available. A time series of ship soundings is discussed in Jordan, et al., (1997). Figures 3 and 4 present a 12 h forecast of winds at 920 mb (vt 8/12 UTC) compared to soundings from the USNS Silas Bent at 06 and 15 UTC. The 920 wind forecast clearly shows the wind shift from southwesterly to northwesterly winds associated with the prefrontal mesoscale circulation. This system is responsible for the weaker stability and outbreak of convection discussed above. At 06 UTC, the Silas Bent is east of the 920 mb wind shift and its sounding indicates an inversion near 600 meters with low level easterly and strong (20 kt) dry southerly winds above the inversion. The aircraft data (Fig. 2) and ship data (Fig. 4) verify the COAMPS forecast of this feature.

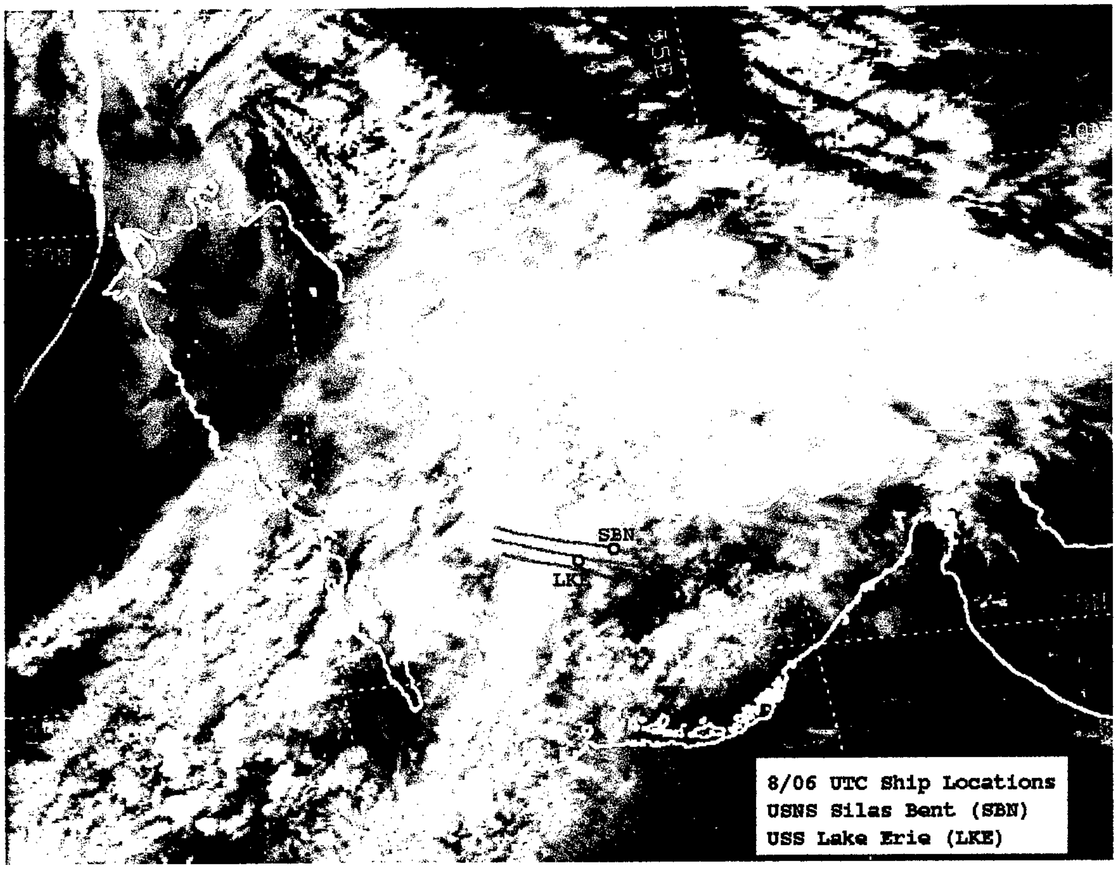

Fig. 1. DMSP (F-12) visible image for 0529 UTC on 8 February 1995. The aircraft cross-section locations are indicated by the lines, and the location of the USNS Silas Bent (SBN) and the USS Lake Erie (LKE) at 06 UTC are indicated by the dots.

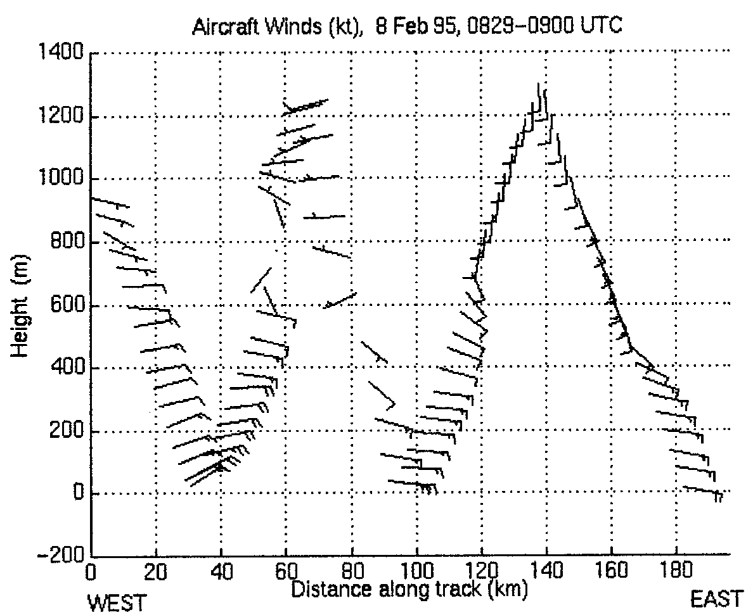

Fig. 2. Cross-section of aircraft measured winds (kt) for 0829-0900 UTC, which is the middle cross-section in Fig. 1.

Jordan, et al., (1997) also showed COAMPS 6 h forecast upward vertical motion along the west edge of the cross section consistent with the convection outbreak.

The effects of the moist, upper level flow from the southwest is evident in the 15 UTC sounding. The entire sounding is quite moist and the winds above 800 meters are steady from the west at 10-20 knots. By 21 UTC (not shown), prefrontal, southerly flow develops below 600 meters. The winds throughout the sounding shift to the west and northwest at 00 UTC on 9 February, which Byers (1995) identifies as the cold front passage and the onset of the Shamal (northwest flow) period.

The 12 h forecast of 920 mb winds (vt 8/12 UTC) by COAMPS (Fig. 3) shows the eastward progress of this system. Ship soundings from the USS Lake Erie at 12 UTC (not shown) and USNS Silas Bent at 15 UTC (Fig. 4) show the perturbation has moved past the ship locations because the winds above the boundary layer have shifted from southerly to westerly. Note also the increase in moisture in both soundings above boundary layer and weakening of the inversion. The COAMPS forecast of these stability, moisture and wind changes continues to be successful, however COAMPS does move the system a little faster than observed. The impact of this feature on EM propagation conditions is discussed in Jordan, et al., 1997. The ability of COAMPS to resolve the structure of this prefrontal mesoscale system is very encouraging.

9 February 1995

During the next 24 hours the cold front moves over the Persian Gulf. DMSP infrared satellite imagery (Fig. 5) at 9/0257 UTC shows the frontal band over the southern part of the Gulf. Note the sharp edge of the rear of the front. The location of the C-130 aircraft cross-section, which started three hours after the time of this image, is denoted by the line on the image.

The aircraft cross-section for 0627-0658 UTC 9 February (Fig. 6) presents a striking view of the thermodynamic and moisture structure at the rear of the front. These data show moisture vertically mixed to the top of the cross-section at the east end but significant drying occurring to the west. A strong subsidence inversion also is present at the base of the dry zone in the potential temperature cross-section. This aircraft cross-section has captured the large changes associated with the rear of the front. Strong subsidence must be present over the western half of the cross-section explaining the drying and formation of a strong inversion above the mixed layer.

Figures 7 and 8 give COAMPS depiction of this cross-section from the 6 h and 18 h forecasts. COAMPS resolves the intense drying (somewhat more intense than observed) over the western portion of the cross-section. Also forecast is the formation of a stable layer under the dry zone over the well-mixed layer in the cold air behind the front. The 18 h forecast of these features is displaced eastward indicating the model is somewhat fast is predicting the motion of the front. But the ability of the model to resolve the vertical motions and resultant vertical temperature and moisture structure at the rear of the front is very impressive.

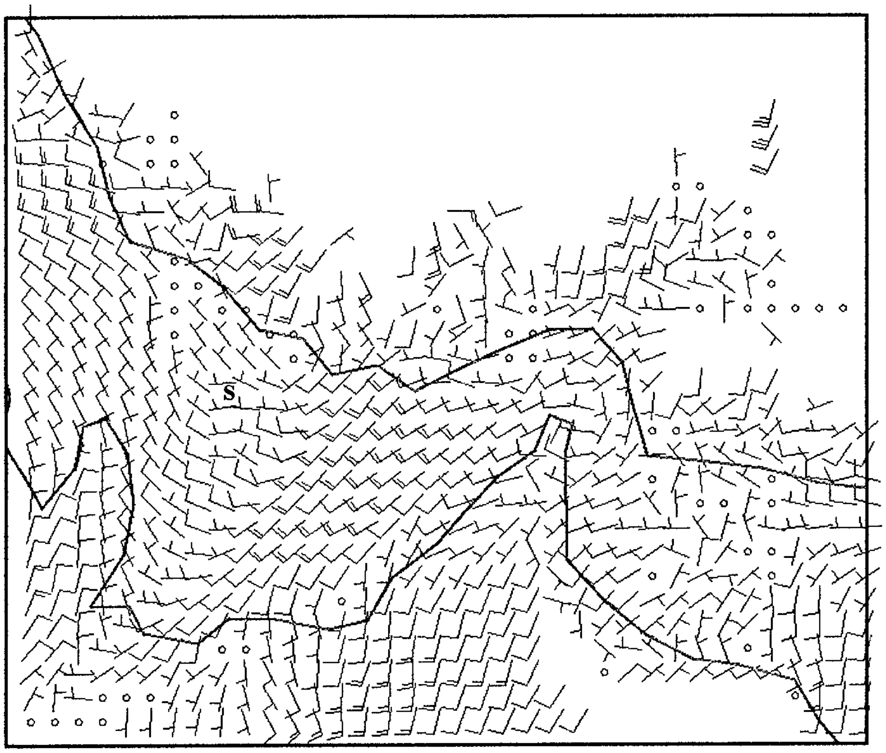

Fig. 3. COAMPS 920 mb winds (knots), 12 hr forecast, valid at 1200 UTC 8 February 1995. The 1500 UTC USNS Silas Bent position is indicated by the letter S. At 0600 UTC, the Silas Bent was located 50 km ESE of the its 1500 UTC location.

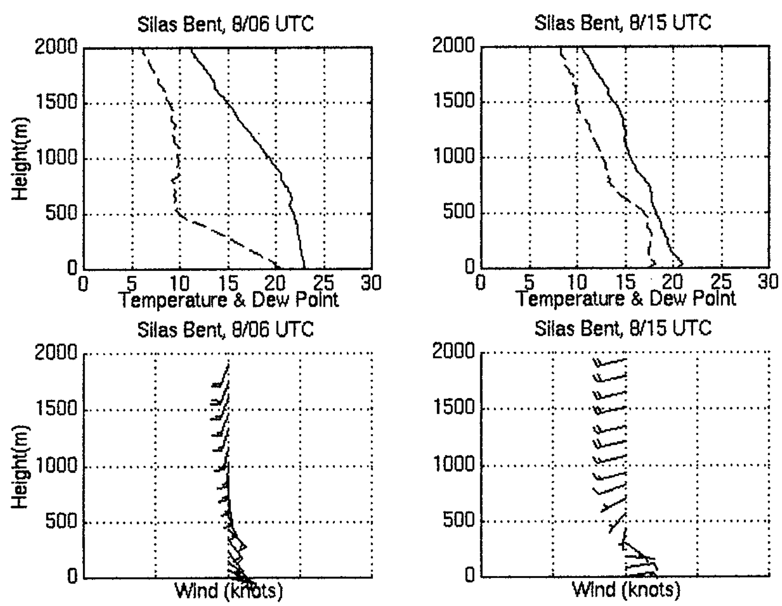

Fig. 4. Rawinsondes for USNS Silas Bent at 0600 UTC and 1500 UTC 8 February, at the locations indicated in Fig. 3. Temperature and dew point (dashed) in Celsius, wind speed in knots. The 920 mb level is at approximately 850 meters.

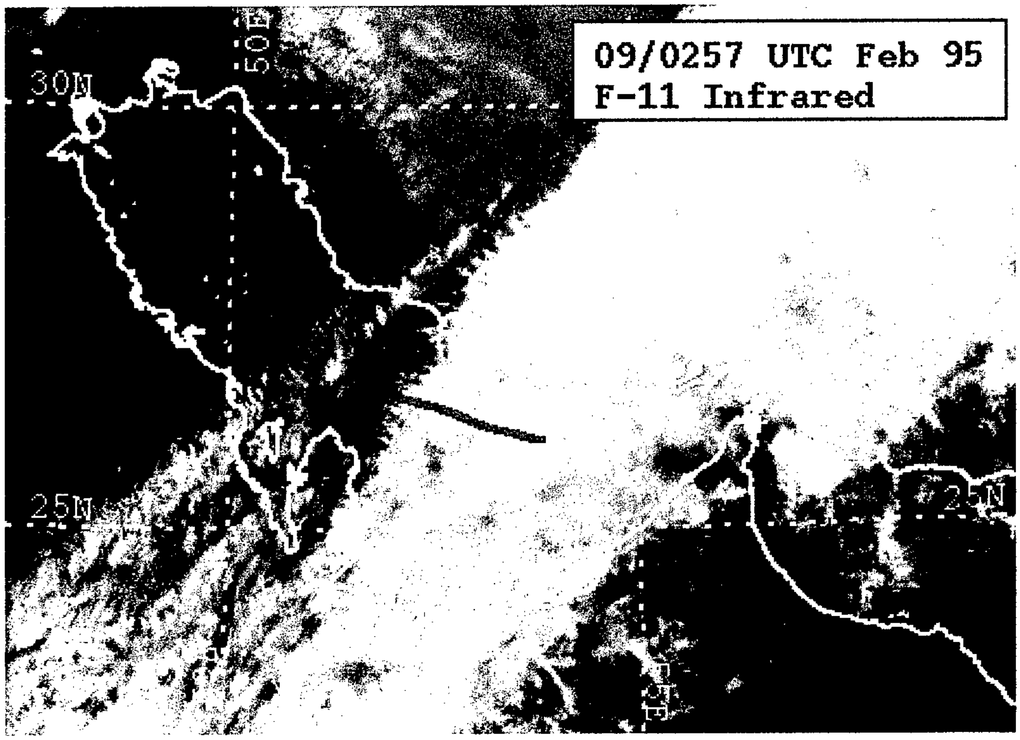

Fig. 5. DMSP (F-11) infrared image for 0257 UTC on 9 February 1995. The aircraft cross-section location is indicated by the line.

11 February 1995

On 11 February, the C-130 measured a deep well-mixed layer to 925 mb that formed during the strong Shamal period following the passage of the front discussed above. The depth of this layer decreases slowly during the day. The 11/0552 UTC sounding from the Silas Bent (Fig. 9, solid line) illustrates this deep mixed layer and the dry air above it. The ability of the COAMPS 6 h and 18 h forecasts to resolve this structure is illustrated by the two COAMPS forecast soundings overlaid on the ship data (Fig. 9). The 6 h forecast is very successful with the deep mixed layer well forecast. The 18 h forecast give the correct general structure but the depth of the mixed layer is forecast more shallow than observed. Study of forecasts from the 10/00, 10/12 and 11/00 UTC model runs do show a trend by COAMPS to forecast too much subsidence and a too shallow mixed layer towards the end of the forecast period. However, the model displays high skill in resolving the mixed layer and inversion structure, which are important to cloud and EM/EO assessment for DOD operations.

CONCLUSIONS

Boundary layer structures during a prefrontal, postfrontal, and deep mixed layer periods over the Persian Gulf were analyzed using aircraft measurements, ship-based rawinsondes, surface observations, DMSP satellite imagery, and COAMPS mesoscale model predictions. The aircraft data revealed a dramatic change in the MABL structures within a 180 km distance for the prefrontal and postfrontal cases. COAMPS mesoscale model predictions did resolve

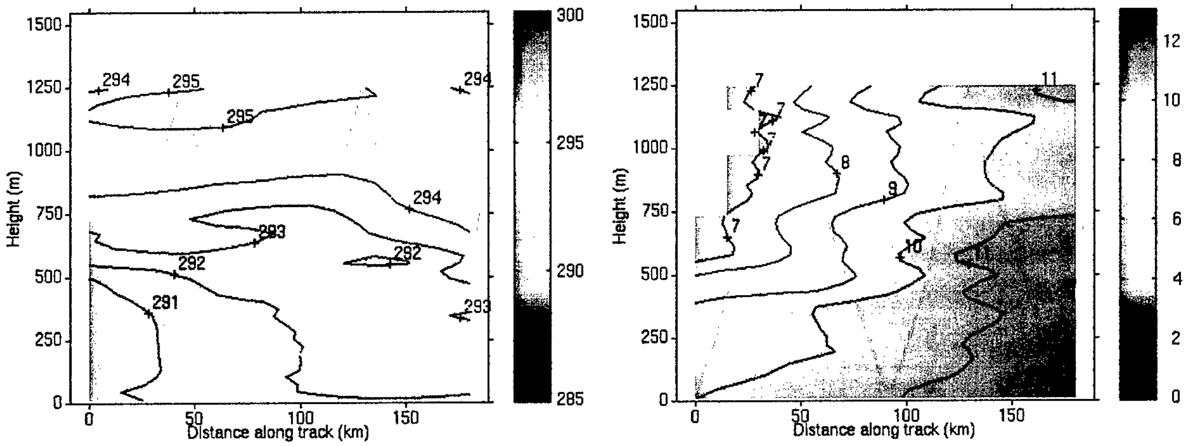

Fig. 6. Aircraft cross-sections of potential temperature (K) and specific humidity (g/kg), respectively, at 0627-0658 UTC 9 Feb 95. The horizontal axis is the distance along the ground track, from west-to-east. The green dotted line indicates the aircraft sawtooth flight path.

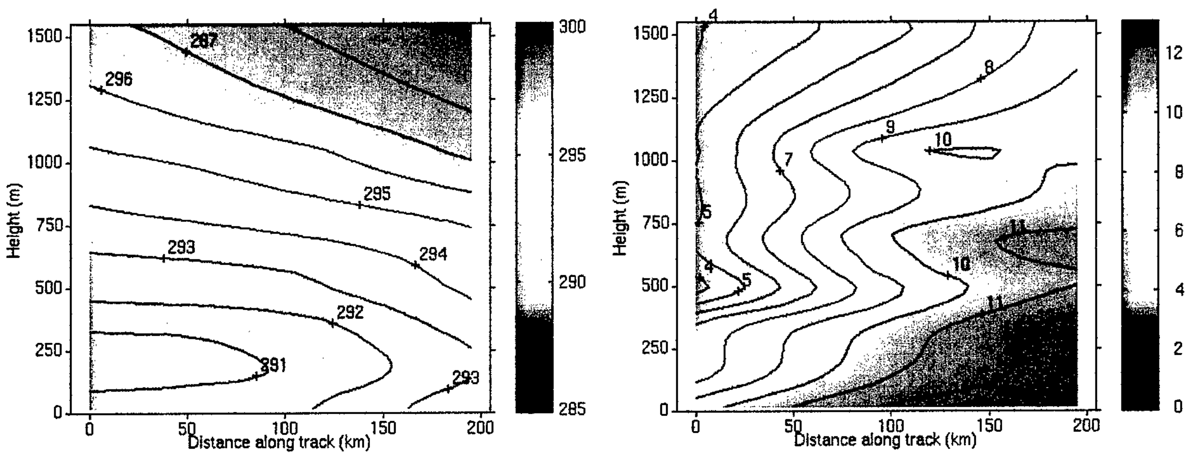

Fig. 7. COAMPS 6 hr forecast of potential temperature (K) and specific humidity (g/kg), respectively, valid at 0600 UTC 9 Feb 95, which is nearly coincident with the cross-section in Fig. X. The horizontal axis is the distance along the ground track, from west-to-east.

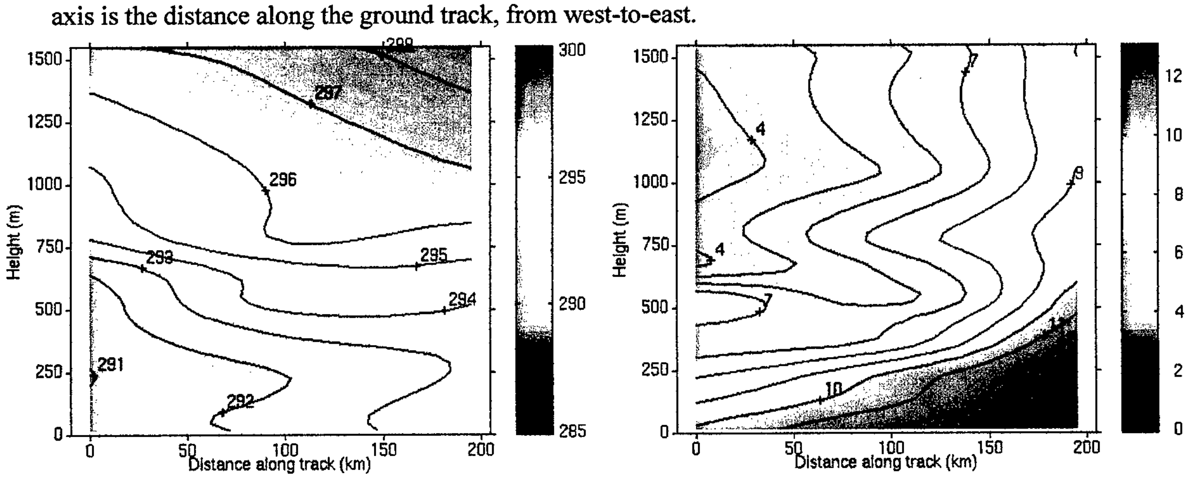

Fig. 8. COAMPS 18 hr forecast of potential temperature (K) and specific humidity (g/kg), respectively, valid at 0600 UTC 9 Feb 95, which is nearly coincident with the cross-section in Fig. 5. The horizontal axis is the distance along the ground track, from west-to-east.

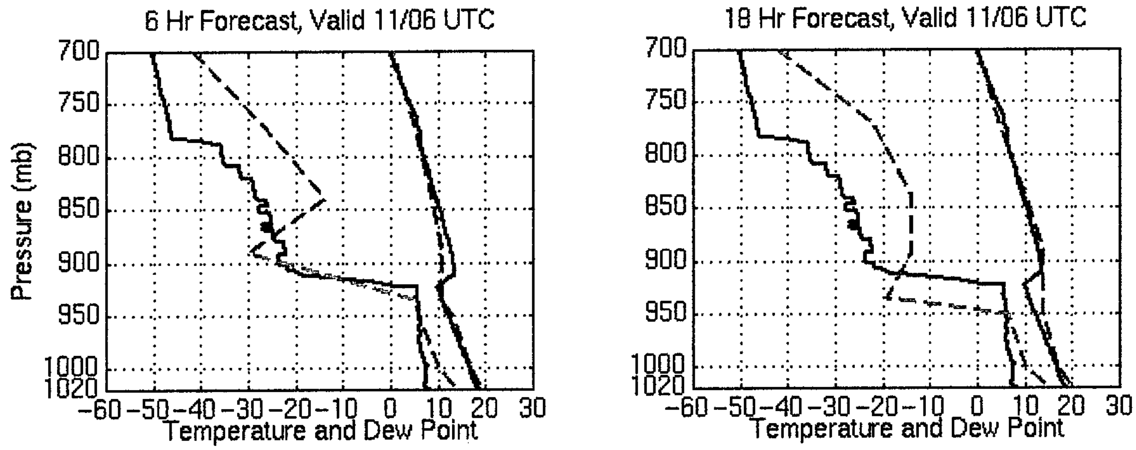

Fig. 9. COAMPS 6 hr and 18 hr forecasts of temperature and dew point, valid at 0600 UTC 11 February 1995, are compared with the 0552 UTC rawinsonde from the USNS Silas Bent. The solid lines represent the Silas Bent (located at 26.1N 53.2E) ; dashed lines represent COAMPS values at 26.0N 53.0E.

important vertical structure of both the prefrontal mesoscale disturbance and rear of the major cold front. This complex structure impacts the assessment of electromagnetic (EM) propagation within this region as well as cloud formation. Successful mesoscale forecasts like these will substantially improve forecasting of clouds, weather, and EM propagation conditions to support DOD operations.

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